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Renewable energy sources in Cameroon: Potentials, benefits and enabling environment

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ABSTRACT

The price of hydroelectricity in Cameroon has recently sky-rocketed. At the same time, firewood in remote areas is being depleted without being replenished. This has led to a number of challenges; energy is no longer affordable and environmental impacts from the wanton exploitation of firewood are widespread. Therefore, there is a need to explore other renewable energy sources which have enormous environmental and energy potentials. However, there is limited scholarly work on the potential of other renewable energy sources in Cameroon. Literature on the potential of renewable energy in Cameroon is still very limited and scattered. The exact sizes of the different renewable energy sources, their benefits and the market potential that can stimulate their uptake are not well-known. Therefore, stakeholders including policy makers, researchers and investors lack guidelines on how and at what level to invest, intervene, and design policies that can lead to the practical exploitation of renewable energy sources. This article investigates the extent to which renewable energy can contribute to the energy sector in Cameroon. The article lays the groundwork that can inform various stakeholders to engage into different activities which can foster the understanding of renewable energy sources and their potentials and limitations. Some key findings are that: while solar and biomass energy are abundant almost everywhere in Cameroon, wind energy is feasible in some selected regions. Furthermore, while the few literature sources about geothermal sources are contradictory or at best non-conclusive about their potential, tidal energy is yet to receive considerable attention, with its first feasibility studies having been just recently begun. These findings point to the fact that if renewable energy is to be part of the Cameroon's energy programme, there is need to scale-up research in the development of renewable energy in order to better inform energy policies.

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1. Background

Cameroon is a sub-Saharan African country, located at the hinge of Africa with smaller and larger portions of its landmass lying in the West and Central African regions, respectively. It covers a total surface area of 475,440 km^2, with an estimated population of 19.7 million (July 2011 estimates by Central Intelligence Agency) [1]. Of this population, 58% live in urban areas with an annual rate of urbanisation at 3.3% between 2010 and 2015. Administratively and geographically, Cameroon is divided into ten different regions. Douala and Yaoundé are the economic and political capitals of two of the regions with the highest populations of 2.053 and 1.739 million respectively [1].

Although most urban regions in Cameroon are electrified, it is still very insufficient and unaffordable to many communities, while rural areas suffer from total lack of power or if it exists it is very minimal. Although some studies by the World Bank estimate urban electricity accessibility at between 45%–50% [2,3], national averages are generally very low. Estimates by Ref. [4], for example, reveal that only 15% and 18% of urban population have access to electricity and domestic gas respectively. This condition is even critical in rural areas where access stands at about 5% [4]. Statistics from the US Energy Information Administration suggest that while there has been a significant increase in total primary energy consumption of about 13.1% (i.e. from 0.086 to 0.099 Quadrillion Btu between 2006 and 2009), the net production has been marginal at only 1.4% increase (i.e. 0.216–0.219 Quadrillion Btu between 2006 and 2009) [5]. Despite these dynamics in the energy consumption pattern, the energy sources have remained unchanged. As of 2008, consumption from hydro renewable sources stood at 4.19 billion kWh with virtually no other form of energy (e.g. geothermal, wind, tidal and wave, biomass and waste) being consumed [5]. Like in most sub-Saharan countries, the demand for energy in Cameroon is acute and poses a serious problem to the government. In fact, it was not uncommon for electricity to be rationed in parts of Cameroon between 1999 and 2005 [6,7]. With regards to the global environmental sustainability issues of sub-Saharan Africa, electricity shortage is not the only problem to tackle. Greenhouse gas emissions have become a top policy agenda item of most governments and developing countries as a whole are now engaged in developing strategies to mitigate greenhouse gas emissions. For example, many strategies are currently being implemented in minimising greenhouse gas emissions through the sustainable management of waste [8,9]. Another example in the mitigation of greenhouse gas emission and provision of energy are strategies aimed at promoting the uptake of renewable energy technologies under the Clean Development Mechanism (CDM) [10]. The adoption of hydro renewable energy as a key source of energy in Cameroon is one of the diversification strategies that could be explored to meet energy demands while at the same time lessening the emission of greenhouse gases. However, the extent to which other renewable energies can potentially contribute to meeting the energy need of Cameroon is still not well-known. Perhaps partly due to the lack of institutional support [11], research to stimulate the uptake of renewable energy has been very limited, not to talk of detailed and elaborate research about the different renewable energy potentials. To determine the renewable energy potential in Cameroon, a good starting point will be to establish the different types of renewable energy sources that exist in the country. This will guide the search for information about: how much the renewable energy has been exploited and how much is left, what can be done to exploit the current renewable energy sources, what are the different structures or facilities in Cameroon that can use renewable energy? However, before focusing on these tasks, an overview of renewable energy will be examined in the ensuing section.

2. An overview of renewable energies

The impacts of climate change are now too evident to be disputed. Although these impacts are being felt all over the world, some studies reveal that sub-Sahara Africa will suffer the most [12,13]. Many governments and international organisations have designed policies and strategies aimed at the mitigation of climate change impacts especially in developing countries. One of these strategies has been the recommendation of the use of renewable energy technologies in the generation of energy. For example, the Clean Development Mechanism is aimed at promoting clean energy development projects in developing countries that can lessen the emission of greenhouse gases.

But what are these renewable energy technologies that can be executed to qualify as a clean development project? According to Szokolay, renewable energy is energy from sources which are naturally replenished or continually available and are not of a finite stock [14]. Although this definition appears unambiguous, there has always been a divergence of opinions as to what sources can be considered 'renewable'. For example, nuclear energy is a highly contested energy source. For example, while World Wide Fund for Nature does not consider nuclear to be renewable [15] most organisations do. It is not in the interest of this article to deal with these conflicting views. However, the most common and generally agreed sources of renewable energy especially with regards to developing countries including Cameroon are sunlight, wind, waterfalls, biomass, geothermal and tide. The different technologies associated with these sources are solar, wind, hydro, combined heat and power, geothermal, tidal energy systems. Solar energy systems harness energy from the sun [16]. Currently, this energy is used in three main ways, passive heat, solar thermal and photovoltaic system. Wind energy systems or wind turbines are renewable energy technologies used in generating energy from wind in motion [16]. Hydro energy systems use energy from moving water, usually by channelling water at a high pressure from the top to the bottom of a dam or by making use of river flows to drive an electricity generator [17]. Combined heat and power is a community heating and electricity system that generates electricity from fuel derived from biomass, organic matter or natural gas [14]. It is important to note that combined heat and power is renewable only when dedicated crops or used forests are replanted. In this case the carbon captured during growth will be equal to the carbon emitted during combustion. Geothermal energy systems refer to systems that capture energy from the earth's core [14]. Tidal systems generate electrical energy by exploiting tidal water flows [14]. Tidal systems can be realised by constructing a tidal barrage in an estuary and operating it as a conventional hydro dam.

3. The rationale for renewable energy sources in Cameroon

Most services in Cameroon depend on the availability of electrical energy. The scarcity of energy therefore inhibits

economic, environmental and social progress of a society. The lack or limited supply of electricity means schools, hospitals, industrial companies, and other state institutions/agencies will not operate optimally [18]. In brief, electricity facilitates the spread of information and communication technology which plays a vital role in the economy of any country.

According to the 2011 CIA figures, 42% of Cameroon's population lives in rural areas while 58% live in urban areas. Despite this significant percentage of the rural population, only 4%–6% have access to electricity [11,19]. Two main reasons account for these low accessibility to electricity in rural areas. Firstly, in most cases, grid extension is practically impossible because of the sparse population, rugged terrain and poor road infrastructural network [20]. This translates to opportunities for off-grid stand alone renewable energy systems to fill this vacuum and provide energy to the rural masses. Secondly, at the moment in Cameroon, grid-connected electricity is expensive and not easily affordable by the rural masses. It has been demonstrated in Ref. [21] that sparsely populated areas with high dispersed households have high grid-connected cost. Furthermore, it has been estimated that in Cameroon, the grid-connection cost of an electricity line for distances of 100 m with two poles of 8 or 9 m amounts to electricity bills of about 7 years and 14 years for high and low energy households respectively [20]. It is therefore important to investigate other readily available renewable energy sources that may not require transmission lines or grid-connection line cost.

The global climate change impacts have become a key topic on the agenda of most governments including the developing countries. Many countries are now being encouraged by international agencies to minimise the amount of greenhouse gases they emit to the environment. Although Cameroon's carbon footprint per capita is far less than the world's average and those of many countries [22], it is apparent that the amount of its carbon dioxide (CO_2) emission from the consumption of energy has been on a rise since the 1980s up to this date [5]. Renewable energy provides opportunities to reduce the amount of CO_2 being emitted to the environment. The exploitation of renewable energy sources in Cameroon can therefore potentially contribute to lessening the emission of CO_2 to the environment.

4. The potential of renewable energy in Cameroon

In this section the quantitative and qualitative potentials of the renewable energy sources will be investigated. As earlier mentioned, lack of institutional support in Cameroon has slowed down research in the renewable energy domain. Consequently, data about a given renewable energy about specific regions will be examined if national data are lacking. The data will be sourced from international organisations' websites, government documents and peer-reviewed documents.

4.1. Solar energy

Cameroon is blessed with an abundance of solar energy resources. In general, the solar energy intensity in the country can be grouped into two categories. First, the highest solar energy intensity is in the Northern and Southern regions of the country with estimates of 5.8 and 4 kWh/day/m^2 respectively [23]. Recent estimates are quite encouraging with the values of 4.9 kWh/day/m^2 possible in the southern regions [24]. As argued by Ref. [24], the conditions for the exploitation of Cameroon's solar energy resources are ideal. In fact, according to Tansi [24], the whole country possesses great solar energy potentials with some regions far above the required average to generate useful energy.

4.2. Wind energy

As earlier alluded to, wind energy resources have never received any considerable attention in Cameroon. Attempts have been made by Refs. [25,26] in assessing the wind potential in Cameroon. These studies were based on meteorological data from the National Meteorological Department located in the Adamaoua and Northern regions of Cameroon. Although the studies focused only on the Northern regions of the country, their outcome clearly indicated that these parts of the country are endowed with enormous wind potentials. This deficiency in studies about wind energy in Cameroon was the rationale behind the recently completed Masters study in the Brandenburg Technical University Cottbus, Germany to further provide an insight into the potential of wind energy towards sustainable economic development as a whole [24]. This particular study concluded that the Northern regions of Cameroon have the highest wind potential. This potential decreases towards the Southern regions, where wind speeds are in a decrease. This conclusion is very much similar to the studies by Refs. [25,26]. These studies also agree on the different wind speeds, which reveal that a town like Garoua in the Northern region experiences wind speed of between 2.8 and 4.1 m/s. On the other hand, Ebolowa, a town located further South, experiences wind speed of the range 1.2–1.8 m/s. While these results reflect a general trend, it is important to conduct field studies in a substantial number of places in order to further estimate with accuracy the potentials of wind energy in Cameroon.

4.3. Hydropower

Cameroon possesses the second largest hydro potential in Africa after the Democratic Republic of Congo (DRC) [6]. The gross theoretical potential of Cameroon's hydropower is 294 TWh/year. Of this amount, 115 TWh/year is considered technically feasible while 103 TWh/year is economically feasible. However, only 5.5% of the technically-feasible capacity has been developed [27]. On the other hand, DRC has a technical feasible potential of 774 TWh/year and an economic feasible potential of 419.21 TWh/year. But only less than 1% of the technically feasible potential has been developed [27]. In terms of the number of plants that exploit the hydropower, three main plants are currently in use in Cameroon. These are the Edea, Songloulou and the Lagdo hydro production plants [28]. The Edea hydropower plant has an installed generating capacity of 263 MW; Songloulou has an installed capacity of 387 MW while Lagdo on the River Benue has an installed capacity of 72 MW [28]. Furthermore, detailed studies conducted by Tchouate [19] reveal a high site hydro potential for possible development of hydropower plants. According to the study, the regional distribution of the potential of hydropower sites is summarised in Table 1.

Table 1
Regional distribution of Cameroon's hydropower potential.
Source: adapted from Ref. [19].

Region	Micro hydro	Major hydro	Total
Adamoua	13	14	27
Centre	8	24	32
East	6	6	12
Littoral	3	11	14
North	0	4	4
North West	8	8	16
West	7	6	13
South	14	8	22
South West	15	8	23
	74	89	163

It is important to note that the hydropower potentials indicated in Table 1 are based on field studies by the Cameroon's Ministry of Mines, Water Resources and Energy. The ministry provides the most reliable up to date information about energy exploitation in Cameroon.

4.4. Biomass energy

Cameroon has the third largest biomass potential in sub-Saharan Africa, with about 66.7% of the total national energy consumed from biomass [24]. Biomass sources can be categorised into wood, agricultural, forest and animal sources. Waste streams from timber factories – which constitute wood source – in the Eastern region are sources that can be utilised to produce power [29]. Rice farms in Ndop, a high degree of soil fertility in the North West region, are all potential areas that can provide straw and plants to be used in a biomass plant [29]. This is an agricultural biomass source. Tree branches and skin from the forest are biomass forest sources. As an animal source, cow dung is an important source of biomass. Based on the fact that different sources constitute biomass, different technologies are involved in their transformation. Therefore, to establish the potential from these different sources, two of the most important biomass technologies—anaerobic digestion and gasification will be investigated.

4.4.1. Anaerobic digestion

This is the breakdown of organic material within a vessel or controlled environment to generate biogas which is about 60% methane and 40% CO_2. The biogas can be used in burning to generate heat and electricity. Animal waste from cows, pigs and poultry, as well as from food processing, agricultural and municipal solid wastes are examples of feedstock that can be utilised in anaerobic digester. Banana cultivation, organic part of urban waste, breweries and food industries, slaughter houses and breeding are different categories of waste identified in Cameroon [30]. A table of values of their different biogas and electricity output has been examined in Ref. [30], hence will not be duplicated here.

4.4.2. Gasification

This is the thermal decomposition of organic material to produce biogas that is used in burning to generate heat and electricity. Residues from wood processing, forest residues, cotton stalks and palm nut shell are potential organic material sources identified in Cameroon that could be used in the gasification process [30]. In cities like Douala, these technologies could even be considered as waste treatment technology and the electricity recovered as a by-product. In fact, all agricultural residues and forest wastes can be gasified. According to Heteu [31], the main criteria that affect the selection of materials for gasification are

- The moisture content should be less than 20%;
- The particle size should preferably be less than 5 cm;
- The ash content should be low and high fusion temperature to avoid clinker formation on the grate.

Studies on the potential of the different biomass sources for gasification are scarce. So far in Ref. [30], some figures for the different biomass sources' potential have been advanced. These are examined in the ensuing paragraphs.

Up to 2003, Cameroon's forests produce about 2.5 million m^3 of timber per year. In the process of felling down trees; branches, roots and skins are left as residues in the forest. These residues constitute a 25%–30% of the exported timber, equivalent to a theoretical potential of 500–700 000 t per year.

A survey of wood industries in Cameroon revealed that residues amount to about 70% of processed timber. Based on studies by Ref. [32], 500 000–800 000 t of residues generate about 176 000–300 000 t of material potentially viable for energy conversion in a gasification plant.

With regards to agricultural residues cotton stalks and palm nuts are available in abundance for gasification. Cotton is cultivated in the Northern region of Cameroon and the annual rate of production was 250 000 t as of 2001/2002 [33]. The residues from this are 500 000–750 000 t which are burnt without being used in a gasification plant [30].

4.5. Geothermal sources

This is one of the areas where there is least published literature in Cameroon. Even in the few writings that exist, data are often contradictory. In Ndinnapoh [34], for example, while it has been argued that the potential for energy from geothermal sources in Cameroon is very low, no numerical figures were used to justify this assertion. Also, figures from the US Energy Information Administration categorically reveal that there is no potential of geothermal energy in Cameroon [5]. However, although studies by the US Department of the Interior Geological Survey suggest the harnessing of geothermal energy in West African States (ECOWAS) is rather uneconomical, it offered a more favourable view about Cameroon [35]. The studies revealed that geo-pressured zones such as the Niger Delta and areas of tectonic activity in the Benue trough and Cameroon have the potential of developing geothermal energy, although the economic conditions were not feasible. Given that tectonic activities are quite common in Cameroon because of the presence of Mount Cameroon, it is reasonable to further investigate how energy that is emitted from the crust of the mountains can be used. In another twist, in other literature, although not through a field study, Saibi [36] identifies Cameroon as a country having some geothermal potential. From the above conflicting views, it is difficult to conclude whether Cameroon has the geothermal energy sources or not.

4.6. Tidal energy

Globally, ocean energy is in its infancy and knowledge about this energy resource is lacking. It is therefore difficult to find a detailed comprehensive study about world tidal power potential. Recent studies by the US Department of Energy indicate that only 40 sites throughout the world have tidal ranges with significant potentials to generate electricity [37]. With regards to Africa, South Africa is the only country that has previously considered tidal energy while Cameroon has so far hired MRS Power Cameroon, a subsidiary of MRS Holding Ltd., a fast growing energy group in sub-Saharan Africa, to conduct a feasibility study on the potentials of tidal energy [38].

5. Impacts of the use of renewable energy technologies in Cameroon

5.1. Environmental and Human health

The use of renewable energy minimises the release of greenhouse gases that can cause damage to the ozone layer or the atmosphere. This implies that the effects on climate cycles are minimised, rendering climate changes more predictable. Furthermore, less greenhouse gases into the atmosphere means less indoor and outdoor air pollution, hence risk to human health is

minimised. The use of renewable energy in homes in place of firewood makes homes healthier, with clean water, cooked food and lower air pollution, thus positively impacting the occupants [39]. In remote areas where there are no grid-lines, renewable energy can be used in medical facilities such as powering fridges and refrigerators for storage of vaccines [39].

5.2. Social harmony and regional peace

The diversification from conventional energy sources such as hydrocarbon to renewable energy implies that more energy is available to meet the country's demand. With increased scarcity of crude oil, social tension which threatens regional peace is now becoming apparent. For example, the oil rich Bakassi Peninsula has been a region of dispute of ownership between the Cameroonian and Nigerian governments [40]. Diversification to renewable energy implies there is a likelihood of minimising these tensions and safeguarding regional peace.

5.3. Economic development

The use of renewable energy in remote areas that would not have had any grid-electricity means the rural masses can manage their small and medium enterprises (SMEs) or micro businesses late into the night. Some of these businesses include running of bars, local night clubs, and evening schools for the adults and school drop-outs. These are all income generating activities that can improve the living standards of the society and the economy of the area. Recent studies by Chien and Hu [41,42] revealed a correlation between the Gross Domestic Product (GDP) of a country and renewable energy. This implies that the investment on renewable energy will have a positive impact on the GDP of Cameroon's economy.

The growth of businesses depends on energy. In Cameroon small businesses such as night clubs depend on electricity. Also, other major industrial companies such as the national oil refinery, SOciété NAtionale de RAffinage (SONARA), the aluminium producing company ALUminium CAMeroun (ALUCAM), sugar producing company SOciete SUcriere du CAMeroun (SOSUCAM), textile and clothing manufacturing company Cotonniére Industrielle du CAMeroun (CICAM) and brewery industries such as Guinness, Les Sociétés Anonymes des Brasseries du Cameroun (SABC), Union Camerounaise des Brasseries (UCB), etc. depend on energy. Some of these companies are highly energy intensive. For example, the aluminium smelting is highly intensive. ALUCAM consumes about 60% of hydroelectricity produced by the two main hydroelectricity plants in Cameroon [24]. This leaves other businesses in dire need of energy. Diversification will imply that energy could be provided to most of the companies and small businesses, which would contribute towards sustainable economic development of the country.

Some studies have revealed that renewable energy projects are likely to create jobs. Although no studies exist for Cameroon about creation of green jobs from renewable energy projects, similar studies in South Africa and Brazil confirm the possibility of green job creation through the use of renewable energy technologies [43–45]. It has also been argued in Ref. [30] that jobs can be created from renewable energy projects. One major importance about the type of jobs is that the jobs involved are not necessarily highly skills-based, hence making it possible for participation of rural communities. For example, the installation of a photovoltaic system may require the use of public transport (driver), while the installation on site would similarly require the services of an electrician and installer. These are jobs that do not require highly qualified personnel and in a situation where it is absolutely lacking, minimal training can be offered in a relatively short time.

6. The market potential for enabling the uptake of renewable energy technologies

The way in which Cameroon government has organised its administrative structure makes it easier and cheaper to promote the uptake of renewable energy technologies. Cameroon is divided into ten main regions. Each region has a capital where most state services are located such as the different delegations that relate with the ministries in the national capital where the executive power is based. Each region is divided into divisions and subdivisions. Sub-divisions are made up of villages. Each of this administrative structure possesses administrative services and where they lack the government is always conducting feasibility studies to expand to remote areas. Moreover, the central government has direct influence on the development and management of these services. Therefore, the government can actually influence decision-making in stimulating the uptake of renewable energy technologies through its services. Some of these services are the regional and delegation headquarters, educational establishment, the health services, the security services, etc.

In the ten different regions, the offices of the different delegations representing respective ministries are potential buildings that can be powered from renewable energy sources. Cameroon has at least 30 ministries, all of which are located in the national capital Yaoundé [46]. Each of these ministries is further broken down into directorates and departments. In periods of energy scarcity, these ministries can be powered through the use of renewable energy technologies to supplement the grid-line electricity provided by Applied Energy Services-SOciété Nationale d'ELectricité (AES-SONEL), the main electricity supplier in Cameroon. At the regional level, each region has all the delegations representing the different ministries. Again, these delegations can be powered by renewable energy as a supplement to grid-line electricity provided by AES-SONEL in periods of scarcity. The educational system offers opportunity for the Cameroon government to embark on the uptake of renewable energy technologies. The country has six state universities, and numerous high, secondary and primary schools. As of 2006, Cameroon's strategy for its education sector was to provide primary education for all by 2015 [47]. This can be achieved if new schools are constructed in rural areas that occupy a high proportion of the population. This can be an opportunity to power these schools with renewable energy technologies. Also, the universities, secondary and high schools can be powered with renewable energy technologies. The use of energy in these institutions is crucial in enhancing learning outcomes as energy can be used in powering laboratories and computers for use by students. The health services are categorised into three levels [48]. These are the central, intermediary and local levels. The central level has the ministry and its different departments. The intermediary and local levels have regional and district hospitals. These structures can be powered by renewable energy technologies. The Cameroonian state places more emphasis on the security of its citizens. There is a good geographical spread of security departments such as police stations, gendarmeries, customs departments, army camps, barracks and prison yards. These departments could improve their services with the exploitation of the electricity generated from renewable energy sources. Some of these departments are in the remote areas that the only logical means of electricity supply is renewable energy as grid lines will cover longer distances and become economically infeasible. In fact, customs' departments, army camps and barracks are usually located at the frontiers with no grid connections. These are potential services that can be powered with renewable energy technologies.

The list of institutions that can be powered through the use of renewable energy systems is huge and cannot be exhaustively

listed. Other institutions include financial institutions, hotels, churches and mosques, and palaces of local chiefs.

The contracts for the development of most of the government institutions cited in this section are often managed by the government through the different ministries. The inclusion of renewable energy technologies in contract specification documents can be considered as one of the ways that can encourage the use of these technologies in the different projects.

7. Conclusion

In this article a survey of international/national literature on most renewable energy sources was conducted. These included the wind, geothermal, tidal, biomass, and solar energy systems. The potential sizes of these sources were quantitatively assessed. For example, numerical or quantitative values of solar intensity such as 5.8 kWh/day/m^2 were used to represent the potential of the solar energy. Other potentials of renewable energy sources were expressed as percentages. For example, biomass consumption was expressed as 67% of the total energy consumption in Cameroon. However, due to extreme lack of research about renewable energy sources in Cameroon, quantitative data could not be found for some, hence qualitative appraisals were conducted. To highlight the importance of renewable energy sources, an overview of some of their impacts on the Cameroon's society were examined. Furthermore, the media/infrastructures (e.g. police stations) through which the uptake of renewable energy systems can easily be stimulated were identified.

Although this article serves as a potential opening for further research, it is important to note that a detailed investigation on sources by sources basis per research project will be very useful in the understanding of renewable energy potentials in the country. This will provide a background on which researchers can conduct field studies and also for policy makers to design and guide the direction in which their renewable energy agenda should take.

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